Design Optimization using Life Cycle Cost Analysis for Low Operating Costs

Khalid A. Khan (P. Eng., MCASI)
Graeme D. Houston (P. Eng., DAR)

Bombardier Aerospace, 123 Garratt Boulevard, N46-11, Downsview, Ontario, Canada M3K 1Y5

With the increase competition among airlines to capture the customer base, more and more airlines demanding the aerospace industry to produce aircraft with high reliability and low maintenance costs. Similarly, aircraft manufacturers that once had the monopoly in various sectors, that is, small & large jets, propellers, business jet are now facing fierce competition. In response to airline industry, manufacturers are increasingly paying more attention to optimize new and current designs to improve reliability while low operating cost aircraft. This paper covers one of several methodologies available to optimize the design of an aircraft. The Life Cycle Cost (LCC) analysis is a powerful tool that has been used extensively on two new designs at Bombardier Aerospace. Several publications are available in public domain covering theoretical aspects of Engineering Economics, including Life Cycle Cost.

The Life Cycle Cost analysis is a systematic approach in applying engineering economics to determine the best solution for a design over the useful life of the aircraft, from an economic standpoint. There are may approaches available in the academic media, however, some of the economic variables that are used in almost all LCC analyses are:

> Cost of borrowing money
> Present Value
> Depreciation
> Break-even point
> Discount Rates
> Interest Rates
> Insurance costs
> Taxes
> Etc.

This paper covers a practical approach to LCC analysis and an in-house developed model is presented here using an example to illustrate the construction and use of the methodology in aerospace industry. However, the computerized model is developed in such a way that minor modification to the model can lead to many other applications outside the aerospace industry.

The LCC analysis methodology and model was developed in 1988 at de Havilland, a division of Bombardier Aerospace, by Reliability & Maintainability Engineering for use in a multi-

disciplinary design environment. It provides a rigorous analysis methodology to evaluate relative merit / benefit and manage risk. In addition, it provides a means of comparing effects of parameter that are normally not compared (For example, weight Vs MTBF).

Life Cycle Costing is a systematic process for identifying the most cost-effective utilization of available resources over the entire product life cycle, that is womb to tomb. The methodology used in the LCC model also allows a systematic process for evaluating and quantifying the cost impacts of various alternative courses of action for the decision makers in engineering, finance and program management.

In order to fully appreciate the value of LCC analysis, it is important to look at the economic evaluation of a product. For a new design project, from conceptual stage, Marketing performs product analysis to determine the type of aircraft and the features for which airlines are willing to pay. The requirements are developed by Marketing and presented to Engineering where the marketing requirements are converted into design requirements and objectives. The market base is also established by Marketing in terms of units that are likely to be sold at a baseline price and corresponding operating costs. From the LCC point of view, for equivalent financial productivity, aircraft price can be traded off against the operating costs as shown below:

Figure 1: Aircraft Price Vs Operating Cost
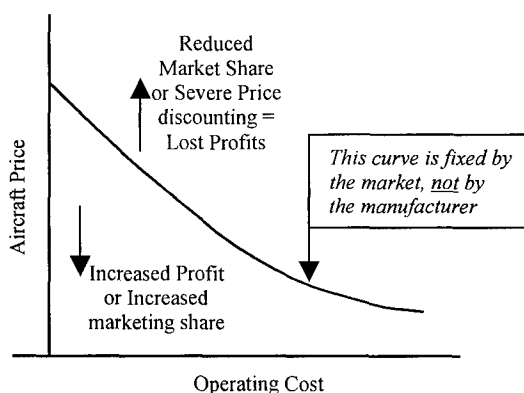
It is apparent from the above chart that as the operating cost increases, the company has only two options, that is, either to discount the price of the aircraft or to improve the operating costs. The operating cost consists of Ownership, Fuel, Crew, Insurance, Maintenance Cost, etc. The ownership costs include financing, spares holding equipment acquisition, etc. The Maintenance Cost is normally 14% to 22% of the operating cost and can be controlled by a cost-effective design.

In order to fully appreciate the usefulness of the LCC analysis, it is important to understand the economic benefit. Cash Flow analysis is perhaps one of the most important tool in the decision making process. The following is a portion of a Cash Flow chart from a program.

Figure 2 – Program Cash
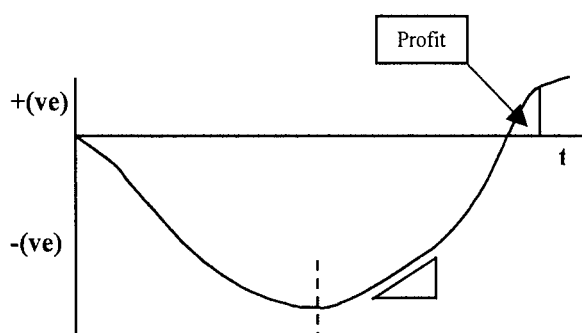
At the onset of a new design or a modification of the existing design, non-recurring costs will drive the negative cash flow. In addition, if recurring costs are not understood and managed properly, the negative cash flow will impact the profitability of the program. Therefore, the slope of the curve is a function of:

Aircraft Price – Cost

Where cost consists of:
- Manufacturing costs
- Bill of Material
- Support

Therefore, in order to maximize the profit, design must be optimized. To have a good and cost effective design, it is imperative to consider all costs from womb to tomb of a product. There are three major areas of costing that covers the entire life cycle of the product. These are:

1. Acquisition Cost

Acquisition costs consists of items such as Research & Development, which includes Initial Planning, Marketing Analysis, Feasibility Study, Engineering Design, etc. Also included in acquisition costs is Production Construction costs such as, Operation Analysis, Facilities, Logistics Support, Customer Support, etc. Some or all of the variables are used in the model depending on the project requirements.

2. Operation and Maintenance Costs

Operation costs are related to the activities required to produce the product for the end user. Typical costs include Production, Marketing & Sales, transportation etc. On the other hand, Maintenance costs are those costs that are incurred in supporting the product. It consists of, Customer Service, Maintenance, Spares, Support Equipment, Modifications, Training, etc.

3. Retirement and Disposal
These costs also fall under product support and consist of costs related to Non-Repairable Items, System/Product Retirement and Material Recycling.

METHODOLOGY

The LCC analysis used at Bombardier provides a rigorous "Bottom Up" work statement driven analysis, that can be compared with program objectives to:

- Close the loop
- Assess Risk
- Determine if further work is required

The methodology allows engineers and program managers to reconcile with program financial analysis to make sound design and/or investment decision.

Application

The basic LCC analysis is applied when:

- There is a requirement to spend money due to some technical or operational requirement and several options are available.

- There is a "Status quo" or existing condition and an investment can be made for some recurring benefit (i.e. Current Cost Reduction Exercise).

- The alternatives are complex and the cost / benefit is unclear, or risk is high.

Normally, the benefits of LCC analysis are most prevalent where large sums of money is involved and several variables, such as procurement cost, manufacturing costs, maintenance costs, etc. can influence the outcome. If the design change is minor and the benefits can readily be identified, an LCC analysis is not required. However, engineers with training in economics, in particular LCC analysis, are known to produce well-balanced design.

LIFE CYCLE COST MODEL

The LCC model requires several steps and inputs from various functions within the organization. For simplicity, the model presented here is for an existing Engine Instrument System consisting of 30 components. Three options are available, each with different recurring and non-recurring costs. The objective of the analysis was to reduce the operating costs and improve the reliability of the system. The benefit was deemed to be increased market share and profit for the aircraft type.

MODEL INPUTS

The following is a list of aircraft and economic variables used in this model and are applicable for the commercial aircraft design.

Base Year: The year project starts. Used in the Cash Flow Analysis.

Market Base: Number of aircraft expected to be sold during the economic study period. Used in the model to calculate Total Program Cost.

Average Fleet Size: The number of aircraft an airline will buy on an average. Is used in the spares cost calculation.

Annual Utilization: Average flight hours per year used in MTBUR, MTBF, NFF and DMC calculations.

Cost of Money: Cumulative effect of elapsed time on money value of an event, based on the earning power of equivalent invested fund. This factor is used to discount the costs to their present values

Economic Study Period: Number of Years the life cycle cost analysis is based on.

Manufacturing Labour Rate: Labour Cost ($/MH) used in the calculation of non-recurring cost and manufacturing installation.

Flight Test Rate (years): Cost of performing a flight test to verify the installation/operation of a component or system ($/Flt hr). Used in non-recurring cost calculation

Spares Holding Factor: Used to calculate the cost of holding the inventory. This cost is part of the operating cost.

Insurance Factor: A factor used for held inventory.

Repair Turnaround Time: Average time in days for an item send to a repair facility, repaired, and returned to the owner. Used in spares requirement calculations.

Airline Labour Rate: Specifically, the labour rate ($/MH) for the maintenance personnel. Used in direct maintenance cost calculation.

Cost of Flight Delays: The cost incurred by airlines to accommodate the passenger due to a delay or cancellation. The information can be obtained from Customer Support.

Annual Inflation Rate: Annual inflation rate expressed as percentage. The inflation rates are available from US Bureau of Labour Statistics on the internet.

Airline Income Tax Rate: Airline income tax rate expressed as percentage. Used to calculation the tax amount that can be deducted from the operating cost.

Depreciation: Percentage decline in value of a capitalized asset for each year. Used to calculation the tax amount that can be deducted from the operating cost.

Cost of Weight: Impacts the performance of the aircraft resulting in lower payload and increased fuel consumption.

Cost of Fuel: Used in the calculation of "Cost of Weight".

Non-Recurring Period: The length of the project including planning, design, certification, manufacturing, installation and delivery of the product.

Spares Margin: Markup on the spares in terms of percentage.

Aircraft Delivery Schedule: Used in the Cash Flow Analysis and to determine the break-even point.

Design Hours: Direct cost by engineering staff for each discipline such as Electrical, Avionics, Hydraulics, etc. Used in the calculation of Non-Recurring costs.

COMPONENT DATA

In addition to the variables listed above, component data is required to calculate the Recurring and Non-Recurring costs. The integrity of the data is important in the LCC analysis to arrive at good results. Sanitized historical data is available from airlines and agencies collecting and processing airline data to produce data/analysis for publications. Most large companies will collect data on an on-going basis to monitor their products. Following is a list of the data used and/or calculated in the model.

Weight: The weight of each component used in the calculations of the operating costs over the economic life of the aircraft.

Purchase Price: The acquisition cost normally has a higher weight on the outcome of LCC analysis. The source of this information is usually the procurement department or can be obtained directly from the supplier.

Spares Price: The spares price is one of the important costs to the end user since the procurement cost is only available to the Original Equipment Manufacturer (OEM). The markup on the spares could be substantial and must be carefully evaluated

and designed to maximize the use of the component in the field.

Mean Time Between Failures (MTBF): This is a calculated value using statistical methods and is based on the component failure and utilization data. An exponential distribution is assumed. This is used in the DMC calculations. MTBF is calculated as follows:

$$MTBF = \frac{\text{Total Flying hours in a period}}{\text{Total Failures}}$$

Mean Time Between Unscheduled Removals (MTBUR): This is a also a calculated data using statistical methods and is based on the component unplanned removal due to a malfunction and utilization data. This data is used in the DMC calculations. MTBUR is calculated as follows:

$$MTBUR = \frac{\text{Total Flying hours in a period}}{\text{Total Unscheduled Removals}}$$

Repair Cost: The average repair cost to restore the component to its design specification. Used in calculating the operating costs.

No Fault Found Cost: This type of expense by the user of the product can be controlled by a good design where Build-in test circuit can avoid removing a good unit from the aircraft. Good troubleshooting techniques built into the maintenance manual can also minimize this cost.

Delay Rate (DR): The number of flights that were delayed beyond the actual departure time plus 15 minutes versus the total scheduled flights. This information is used in the calculation of Delay cost. The delay rate is calculated as follows:

$$DR = \frac{\text{Total Flights delayed in a period}}{\text{Total Flights; same period}}$$

Downtime Rate (DTR): The time aircraft is not available for revenue service due to a component malfunction causing delay. The downtime rate is calculated as follows:

$$DTR = \frac{\text{Total Downtime in a period}}{\text{Total Delays; same period}}$$

Spares Exposure (SE): The spares exposure is based on the Poisson Distribution and is used to calculate the spares required by the airlines to operate their fleet. The spares exposure is calculated as follows:

$$SE = \frac{TAT * AU * AFS * QPA * 1/MTBUR}{365}$$

Where,
TAT=	Turnaround Time (days)
AU =	Annual Utilization (Flight Hours)
AFS=	Average Fleet Size (No. of aircraft)
QPA =	Quantity Per Aircraft

Note: If the MTBUR is infinite then spares exposure is zero.

Manufacturing/Installation Cost (MIC): The time required by production labour to manufacture and/or install the component on the aircraft. MIC is calculated as follows:

$$MIC = \text{Manuf/Installation time (hours)} * \text{Labour Rate}$$

Spares Required (SR): The spares required to support the continuous operation of the product. In an ideal situation, if the component life is equal to the economic life of the product where the aircraft will be scrapped, then spare requirements will be zero. Also, If the MTBUR is infinite and the unit does not malfunction until the scheduled maintenance, then the spare requirement will also be zero.

Using Poisson Cumulative Distribution Chart, for 95% probability and spares exposure "SE", the spares required can be read off the chart. Alternatively, the following computer sub-routine can be used to have the model calculate the spares requirement:

$$S = 0 \qquad \text{(Number of Spares)}$$
$$R = 0 \qquad \text{(Probability)}$$
$$R = R + \frac{\text{Spare Exposure}^S \times e^{-\text{Spares Exposure}}}{S!} \qquad (1)$$

if $(R > 0.95)$ then Spares $= S$, otherwise $S = S + 1$ and goto (1)

where

Spares Exposure = Repair Turn Around Time (Days)$\times$
Annual Utilization (flts - hrs)$\times$
Average Fleet Size $\times$
Quantity per Aircraft/365
and
assuming that 95% of time, all spares requirements can be satisfied.

Direct Maintenance Cost (DMC): The cost resulting from all direct maintenance performed on the component to restore it to its functional state. DMC is calculated as follows:

$$DMC = \left\{ \left(\frac{1}{MTBF} \times \text{Repair Cost} \right) + \right.$$
$$\left(\frac{1}{MTBUR} - \frac{1}{MTBF} \right) \times \text{NFF Cost} +$$
$$\left(\frac{1}{MTBUR} \times \text{Line Labour Manhours} \right) \times$$
$$\left. \text{Airline Labour Rate} \right\} \times QPA$$

Delay Cost (DC): The cost of delay is significant to the airlines due to lost revenues and customer base. The delay cost is calculated as follows:

$$DC = DR * DTR * \text{Expenses due to delay}$$

Spares Cost (SC): The cost of Spares is calculate as follows:

$$SC = SR * \text{Spares Price}$$

SUMMARY OF COSTS

In general, the LCC model uses inputs typical of those generated by the functional departments in response to defined work statement such as non recurring man-hours and material, equipment purchase costs including the cost of spares, manufacturing labour costs, equipment reliability and repair costs, etc. at the system / component level. In addition, there are inputs that have a more global effect, and tend not to vary much for any given program. These are typically things like the cost of money, number of aircraft in a program, anticipated delivery rate, etc. Note that all inputs are treated as variables in the model. The total Life Cycle Cost in the model is summarized in Figure 3 and 4 by aircraft and by program respectively.

Figure 3 – Life Cycle Cost Summary by Aircraft

COST ELEMENT	Baseline	Option 1	Option 2	Option 3
Non-Recurring Program		$350,000	$250,000	$450,000
Non-Recurring per Aircraft		$1,750	$1,250	$2,250
Component Cost per Aircraft	$56,656	$45,440	$40,360	$50,520
Labour Cost per Aircraft	$18,880	$7,200	$7,200	$7,200
Initial Spares Cost per Aircraft	$7,816	$5,240	$4,640	$6,040
INVESTMENT COST/AIRCRAFT:	$83,352	$59,630	$53,450	$66,010
Direct Maint. Cost per Aircraft (Yr 0)	$11,814	$3,911	$3,911	$3,911
Delay/Cancellation Cost/Aircraft (Yr 0)				
Spares Holding Cost per Aircraft (Yr 0)	$782	$524	$464	$604
Insurance Cost per Aircraft (Yr 0)	$378	$272	$244	$300
Fuel Cost-Weight per Aircraft (Yr 0)	$2,508	$914	$914	$914
Miscellaneous (Yr 0)				
TOTAL OPERATING COST/AC (YR 0)	$15,482	$5,621	$5,533	$5,729
15 YR OPERATING COST/AC (S)	$132,518	$48,112	$47,360	$49,036
Depreciation (S/Yr)				
Tax Adjustment (Yr 0)				
TOTAL LIFE CYCLE COST/AC	$215,870	$107,742	$100,810	$115,046

The total operating cost per aircraft in Figure 3 is distributed over the life of the product (15 years in this example) and discounted to convert yearly cost into present dollars, that is, Present Equivalent Value (PEV). Standard financial formula (Cost of Money – see Inputs) is used to calculate PEV in this model. An example is presented here in Figure 4

Figure 4 – Operating Cost Analysis

	Baseline:	Baseline System			
YEAR	YEAR 'n' ($)	CUMULATIVE P.E.V ($)	DISCOUNT FACTOR YEAR 'n'	OPER COST YEAR 'n'	TAX ADJ. YEAR 'n'
0	83,352	83,352	1.0000	0	0.00
1	14,335	97,687	0.9259	15,482	0.00
2	13,273	110,961	0.8573	15,482	0.00
3	12,290	123,251	0.7938	15,482	0.00
4	11,380	134,630	0.7350	15,482	0.00
5	10,537	145,167	0.6806	15,482	0.00
6	9,756	154,924	0.6302	15,482	0.00
7	9,034	163,957	0.5835	15,482	0.00
8	8,364	172,322	0.5403	15,482	0.00
9	7,745	180,066	0.5002	15,482	0.00
10	7,171	187,238	0.4632	15,482	0.00
11	6,640	193,877	0.4289	15,482	0.00
12	6,148	200,026	0.3971	15,482	0.00
13	5,693	205,718	0.3677	15,482	0.00
14	5,271	210,989	0.3405	15,482	0.00
15	4,881	215,870	0.3152	15,482	0.00
TOTAL	132,517.67		8.5595		

In order to launch a program, the investment costs and operating costs must be clearly understood at the program level by business and financial mangers. Therefore, the program cost is calculated by multiplying the number of aircraft (as dictated by the program) by the aircraft level costs as shown in Figure 5.

Figure 5 – Life Cycle Cost Summary by Program

COST ELEMENT	Baseline	Option 1	Option 2	Option 3
Non-Recurring Program		$350,000	$250,000	$450,000
Recurring Program:				
Component Cost	$11,331,200	$9,088,000	$8,072,000	$10,104,000
Labour Cost	$3,776,000	$1,440,000	$1,440,000	$1,440,000
Initial Spares Cost	$1,563,240	$1,048,000	$928,000	$1,208,000
TOTAL INVESTMENT COST:	$16,670,440	$11,926,000	$10,690,000	$13,202,000
TOTAL OPERATING COST - FLEET:	$26,503,533	$9,622,473	$9,471,998	$9,807,187
TOTAL PROGRAM COST:	$43,173,973	$21,548,473	$20,161,998	$23,009,187

ANALYTICAL MODEL OUTPUTS

1. Life Cycle Costs

Based on the input values, the model computes the Life Cycle Costs from the aircraft Operator's standpoint on a "per aircraft" basis. The model attempts to capture the costs of particular options from "womb to tomb". A typical example is shown in Figure 6.

Figure 6 – Life Cycle Cost Comparison
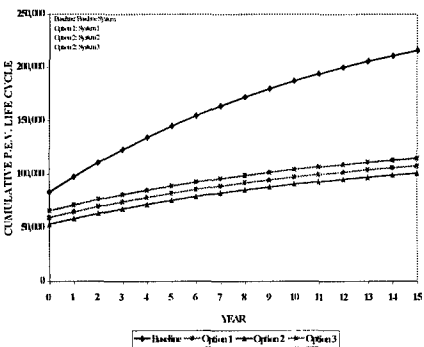
The "Year 0" value on the graph represent the operator's investment, including the appropriate share of the non-recurring, the cost of equipment and installation, and the cost of initial provisioning. The graph displays the investment cost and the cumulative operating costs. The 15 year values represent the total Life Cycle Cost for the particular option, in "present value" dollars, since this is the only way to fairly compare options where investment and operating costs can vary significantly.

2. Cash Flow

The Cash Flow Analysis has been designed specifically for the situation described earlier, where there is a baseline (status quo), (existing instrument system with approximately 30 components), and we are considering investing in a new instrument system for some benefit. The model has been designed to compare three alternatives to the declared baseline in a manner such that for any given option, non-recurring costs are evenly distributed over a specified period, and then the investment is recovered (or not) as a function of the cost savings per aircraft of the new system.

For the cash flow analysis, aircraft recurring and program non-recurring costs are used and distributed over the cash flow analysis period. A sample of the cost distribution worksheet is presented in Figure 7.

Figure 7 – Cash Flow Analysis Worksheet

	Baseline	Option 1	Option 2	Option 3
NON-RECURRING/PROGRAM:	0	350,000	250,000	450,000
RECURRING/AIRCRAFT:	72,957	50,911	46,029	55,727
NON-RECURRING MONTHS:	0	12	12	12

Baseline:

MON	PLANNED DELAY	ACTUAL DELAY	CUM DELAY	CASHFLOW BY MONTH	YEAR END TOTAL
1	2.00	2.00	2.00	-145.913	
2	2.00	2.00	4.00	-145.913	
3	2.00	2.00	6.00	-145.913	
4	2.00	2.00	8.00	-145.913	
5	2.00	2.00	10.00	-145.913	
6	2.00	2.00	12.00	-145.913	
7	2.00	2.00	14.00	-145.913	
8	2.00	2.00	16.00	-145.913	
9	2.00	2.00	18.00	-145.913	
10	2.00	2.00	20.00	-145.913	
11	2.00	2.00	22.00	-145.913	
12	2.00	2.00	24.00	-145.913	-1,750.960

Option 1:

| MON	PLANNED DELAY	ACTUAL DELAY	CUM DELAY	CASHFLOW BY MONTH	DELTA CASHFLOW BY MONTH	CUM DELTA CASHFLOW BY MONTH	YEAR END TOTAL
1	2.00	0.00	0.00	-29.167	-29.167	-29.167	
2	2.00	0.00	0.00	-29.167	-29.167	-58.333	
3	2.00	0.00	0.00	-29.167	-29.167	-87.500	
4	2.00	0.00	0.00	-29.167	-29.167	-116.667	
5	2.00	0.00	0.00	-29.167	-29.167	-145.833	
6	2.00	0.00	0.00	-29.167	-29.167	-175.000	
7	2.00	0.00	0.00	-29.167	-29.167	-204.167	
8	2.00	0.00	0.00	-29.167	-29.167	-233.333	
9	2.00	0.00	0.00	-29.167	-29.167	-262.500	
10	2.00	0.00	0.00	-29.167	-29.167	-291.667	
11	2.00	0.00	0.00	-29.167	-29.167	-320.833	
12	2.00	0.00	0.00	-29.167	-29.167	-350.000	-350,000

The yearly cash flow for each option is then compared with the baseline and the delta Present Equivalent Value is calculated for each year in the cash flow study periods shown in Figure 8. These values are then used to construct the cash flow chart for analysis.

Figure 8 – Cash Flow Comparisons

YEAR	Baseline: YEAR END TOTAL	Option 1 vs Baseline YEAR END DELTA	Option 2 vs Baseline YEAR END DELTA	Option 3 vs Baseline YEAR END DELTA	Option 1 vs Baseline DELTA P.E.V.	Option 1 vs Baseline DELTA CUM P.E.V.
0	0	0	0	0	0	0
1	-1,750,960	-350,000	-250,000	-450,000	-324,074	-324,074
2	-1,969,830	-595,238	-727,052	-465,206	-510,321	-186,247
3	-1,969,830	-595,238	-727,052	-465,206	-472,519	-658,766
4	-2,188,700	661,376	807,836	-516,896	-486,131	-1,144,897
5	-2,042,786	-617,284	-753,980	-482,436	-420,113	-1,565,010
6	-1,969,830	-595,238	-727,052	-465,206	-375,101	-1,940,111
7	-1,605,046	485,009	-592,413	-379,057	-282,998	-2,223,109
8	-1,605,046	485,009	-592,413	-379,057	-262,035	-2,485,144
9	-1,021,393	-308,642	-376,990	-241,218	154,398	-2,639,542
10	-583,653	176,367	-215,423	-137,839	-81,692	-2,721,234
11	-583,653	-176,367	-215,423	-137,839	75,641	-2,796,874
12	-583,653	-176,367	-215,423	-137,839	-70,038	-2,866,912
13	-583,653	176,367	-215,423	-137,839	-64,850	-2,931,762
14	-583,653	176,367	-215,423	-137,839	-60,046	-2,991,808
15	-583,653	-176,367	-215,423	-137,839	-55,598	-3,047,406
16	-583,653	-176,367	-215,423	-137,839	51,480	-3,098,886
17	-583,653	-176,367	-215,423	-137,839	47,666	-3,146,552
18	-583,653	176,367	215,423	-137,839	44,136	-3,190,688
19	-583,653	-176,367	-215,423	-137,839	40,866	-3,231,554
20	-583,653	176,367	215,423	-137,839	37,839	-3,269,393

Figure 9 below displays the non-recurring expenditure, until the new system cuts in, at which point, the graph displays the cumulative difference in recurring costs between an option and the baseline. The graph depicts the net present value of a given investment at any point in time, and the break even point is indicated where a curve crosses the x-axis. In the example below, all three alternatives represent the new instrument system, however, each used a different non-recurring cost, and a different procurement cost.
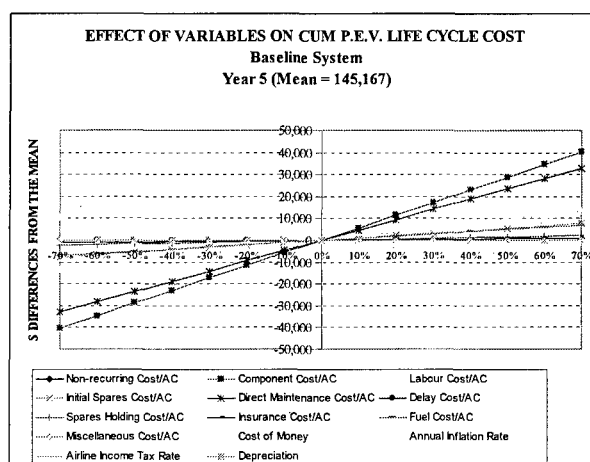
Figure 9 – Cash Flow Comparisons
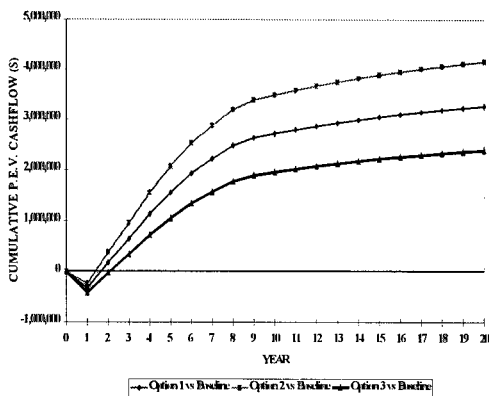
THE POWER OF ANALYTICAL MODELLING

The true power of the model becomes evident once the inputs have been entered. Although the inputs are treated as "hard" numbers, at the conceptual / preliminary phase of the program, they are anything but hard numbers. In fact, apart from existing configurations with established historical data, the inputs are predictions, each with its own degree of uncertainty.

Sensitivity Analysis

The model has a built in sensitivity analysis where iterative process is used to change one variable at a time while holding the rest constant. In this particular example, the program goes through approximately 92,000 iterations to generate Cash Flow charts for each year against the variation criteria used, such as ± 0% to 70%. An example is presented in Figure 10, below:

Figure 10 – Sensitivity Analysis

EFFECT OF VARIABLES ON CUM P.E.V. LIFE CYCLE COST
Baseline System
Year 5 (Mean = 145,167)

While at first glance this might appear to be a crude approximation, it matches the precision of the inputs one is likely to receive, and as long as the "mean" lies in the middle of the distribution, the assumption of a normal distribution has merit. It is now possible to generate an output distribution for a particular project or opportunity. For example purposes, the distribution is superimposed on the Engine Instrument example in Figure 11 below

Figure 11 – Cash Flow Comparisons

Depending on the end result of interest, it is relatively straightforward to determine cost driving parameters. As a matter of practice, it is prudent to explore a range of input values for the cost drivers in order to test the sensitivity of the result to that variation. In addition, this should be repeated for inputs with the highest degree of uncertainty. The cash flow example in this paper exemplifies this type of exploration where a ± 30% variation in non-recurring costs exerts little influence on the result, but ± 10% variation in the procurement cost of the new instrument system has a marked effect.

Depending on the desired level of savings, a "must not exceed" purchasing cost can be established. On the other hand, if a cost driver had a high degree of uncertainty, it may be worthwhile to conduct a more detailed evaluation to reduce the uncertainty. In any event, the model has been designed to cater to "what if" types of exploration at the push of a button, permitting efficient assessment, and management of risk.

Note that the model has been described in terms of a "systems" level analysis. However, any number of these can be rolled up to a program level analysis.

This process can be applied to several different projects and the results superimposed on one another as shown in figure 12 below. Since the curves for the two projects are mathematically defined, numerical assessment of risk is possible once consequences are established.
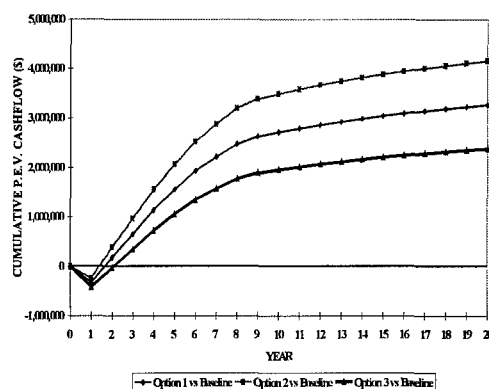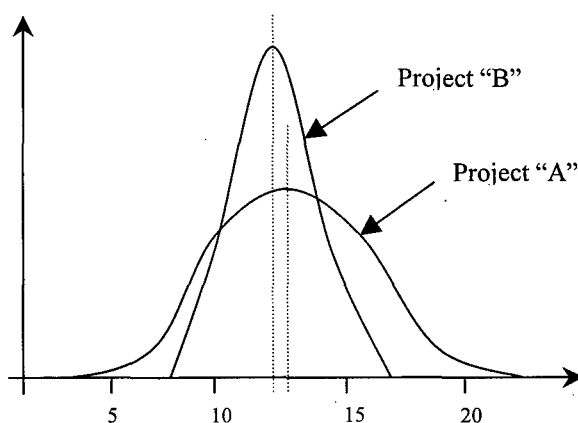
Figure 12 – Risk Assessment

RISK ASSESSMENT

In its present form, the model treats the inputs as exact values, and computes an exact output. In reality, each input represents a "point estimate", or mean value, with its own variation. However, it is possible to use the model as a foundation for numerical risk assessment, as follows:

For each input, three values are obtained; optimistic, expected, and pessimistic. These inputs are used to create three scenarios, that is, most favourable, expected, and least favourable. These can be considered analogous to +3 sigma, mean, and −3 sigma for a normal statistical distribution.

CONCLUSION

Life Cycle Cost Analysis is a powerful tool used to optimize the design for increase profitability and market share. It is a structured process that allows the user to collect and analyze all aspects of the design and financial variables to realize a well-balanced product.

In Aerospace industry, Life Cycle Costing is becoming increasingly important since airlines are no longer willing to pay for inefficient design and high operating costs.

Engineering can play a major role in increasing profit through LCC analysis. At the conceptual design stage, this type of study can be used to select a most LCC efficient configuration. That is lowest Bill of Material for the best economic value.

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